

FINAL PROGRESS REPORT

Contract No. NASW-24264

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Summary of Work Accomplished:

Work accomplished on contract NASW-24264 between 22 March 2001 and 21 March 2002 2001 is described below. Key abstracts are attached.

Project 1: Detailed Crustal Stratigraphy from Central Peaks Measurements

- Clementine imagery for 9 complex craters extracted and mosaicked from USGS UVVIS datasets; completed spectral mixture analysis on 6 of 9 craters.
- Analyses of Tycho crater topography, immaturity, and apparent reflectance interactions completed [Tompkins and Hawke, 2001]. Publication in preparation.
- Prepared text for draft of book chapter for *New Views of the Moon* project.
- Invited presentation prepared for the New Views of the Moon – Europe workshop.
- Completed initial spectral analyses of regions around Stevinus Crater and Jackson Crater; created shade-free reflectance image for processing and presented results at 33rd LPSC [Tompkins, 2002].
- Evaluation of extraction of high-resolution spectra by combining multispectral images and point telescopic spectra continued [Sunshine and Tompkins, 2001].

Analysis Summary:

The main direction of research as proposed concerned determining crustal composition through the examination of impact crater central peaks. This year of research continued more focused, regional studies of selected craters including Tycho, Crookes, Ohm, Vavilov, Stevinus, and Jackson. The accomplishments with respect to this work include:

- (1) Research into the effects of topography on the derivation of geochemical and mineralogical estimates from multispectral data. Stevinus incidence angles were derived both a linear and a non-linear spectral mixture model (in which a shade component serves as a proxy for the incidence angle). The data were then corrected for topographic effects, and FeO abundances were calculated from the corrected data. Previous results for the crater Tycho had indicated large underpredictions (i.e., overcorrections of topographic effects) of FeO [Tompkins and Hawke, 2001], but were later shown to be consistent with Lunar Prospector FeO maps. The corrected Stevinus FeO map is also consistent with Lunar Prospector results, but the method still requires quantitative accuracy assessment. This will be accomplished using actual high-resolution DEM data.
- (2) Our understanding of Tycho's composition has been found to be affected by Tycho's extreme immaturity. The crater's relatively high albedo is causing FeO estimates based on Clementine data that are at odds with estimates based on Lunar Prospector gamma-ray estimates. The differences – and their causes – need to be resolved, and extended to other lunar craters [Tompkins and Hawke, 2001].
- (3) The crater Copernicus was used as a test case for a new approach to combining high spatial resolution multispectral images with high spectral resolution point spectrometer data, to increase the apparent spectral information for an overall scene [Sunshine and Tompkins, 2001].

References:

- Sunshine, J.M., and S. Tompkins, Yet another look at Copernicus: Projecting telescopic spectra onto Clementine multispectral images through spectral mixture analysis (abstract), *Lunar and Planetary Science Conference XXXII*, 2001.
- Tompkins, S., Indications of magma ocean variability in fresh highland craters (abstract), *Lunar and Planetary Science Conference XXXIII*, in press, 2002.

Tompkins, S., and B.R. Hawke, Distribution of materials at Tycho Crater (abstract), *Lunar and Planetary Science XXXII*, 2001.

Introduction: Analyses of global remote sensing data for the Moon (from Clementine and Lunar Prospector) have served to confirm the view that the lunar highlands are dominated by anorthosite [1-3]. Thus it is of particular interest to understand the distribution and origins of any atypical (gabbroic, noritic, or troctolitic) lithologies that appear within the highlands. The Clementine UVVIS camera data allow for the detection and characterization of such lithologies, particularly within the central peaks and walls of large impact craters, where subsurface stratigraphy can be inferred from surface materials. Korotev [4] suggests that the atypical lithologies are unlikely to be related to the Mg-suite, and thus these craters may provide insight into the compositional variability within the crust formed from the magma ocean or through subsequent magmatic activity.

Data: Clementine UVVIS camera multispectral images for seven complex, highland craters (Table 1) have been extracted from USGS-produced global Clementine mosaics. The craters are all young (Copernican) and have been previously identified as containing mafic lithologies within their central peaks (Table 1), which are believed to contain material from beneath the megaregolith [5].

crater	lat	lon	diam (km)	Peak lithologies
Jackson	22°N	197°	71	GNTA, AGN
King	06°N	120.5°	75	GNTA, AGN
Ohm	18°N	246°	64	GNTA, AG
Crookes	10.5°S	195°	50	GNTA, AT
Stevinus	33°S	54.5°	75	GNTA, AG, AGN, AN
Tycho	43°S	349°	85	GNTA, AG, AGN, G
Vavilov	01.5°S	221°	99	A, GNTA, AGN

Table 1: Highland craters for which mafic central peaks compositions have been identified [2]. Rock type abbreviations are: A (anorthosite), GNTA (gabbroic-noritic-troctolitic anorthosite, with 80 - 90% plagioclase), AN (anorthositic norite), AGN (anorthositic gabbro-norite), AG (anorthositic gabbro), N (norite), G (gabbro), and AT (anorthositic troctolite).

At these craters, estimates of mineralogy and surface chemistry using approaches outlined by Tompkins and Pieters [2] and Lucey *et al.* [6] allow for first order identification and characterization of spectrally distinct units from Clementine data. Initial results for two of the craters are presented below.

Preliminary Observations: Three-color composites of Stevinus and Jackson (Figures 1 and 2) high-

light areas of higher mafic content, and differentiate between fresh and mature materials. The two images have been scaled identically, so variations in color between the two images are real. In Figures 3 and 4 are reflectance spectra selected from key locations within and around each crater.

Stevinus. The crater Stevinus is believed to contain multiple lithologies within its central peaks [2], including anorthositic gabbro and anorthositic norite exhumed from 11 - 12 km [5] beneath the pre-impact surface. An examination of the entire crater and its surroundings (Figure 1) suggests that the mafic material extends to near-surface depths, where it is found within the crater rim and walls. Furthermore, the mafic material may extend laterally on a regional scale, as suggested by the composition of the small fresh craters to the NW and SE of Stevinus (Figure 3). As calculated from the Lucey *et al.* [6] approach, FeO ranges from 0 - 9 wt.% in and around the crater (areas of steep topography were not included), with the peaks and walls typically between 7 and 9 wt.% and floor between 7 and 9 wt.%.

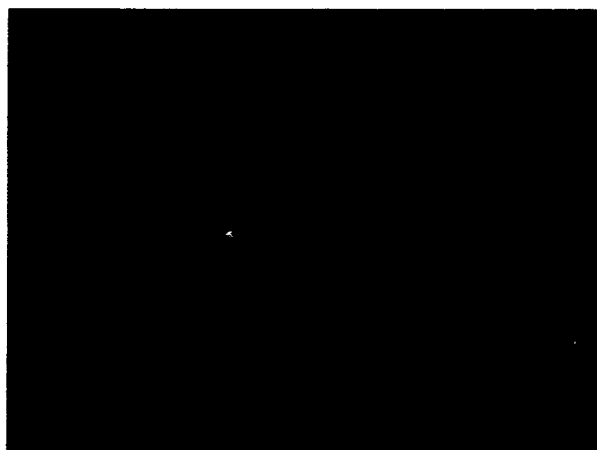


Figure 1: Red: .75μm/.4μm ratio, Green: .95μm/.75μm ratio, Blue: .4μm/.75μm ratio. Red areas are optically mature, while blue areas are relatively fresh. Green indicates areas of higher mafic content. North is up, and the scene is ~327 km across.

Jackson. Similar in size, Jackson's central peak material is also likely to come from 11 - 12 km beneath the surface. A comparison of Figures 1 and 2 suggests that Jackson is more anorthositic than Stevinus. The central peak and north wall spectra have shallower (though still prominent) absorption bands. The peaks and walls also contain outcrops that are distinctly more anorthositic in composition (blue in Figure 2, represented by the E. wall spectrum in Figure 4).

and there are no indications of shallow mafic units outside the crater (i.e., 2 – 3 crater radii away). Jackson's calculated FeO values are typically ~2 wt.% lower than at Stevinus, with the peaks and walls at 5 – 7 wt.% and very small outcrops as high as 9 wt.%.



Figure 2: Color scheme is the same as for Figure 1. The black box indicates missing data. North is up, and the scene is ~220 km across.

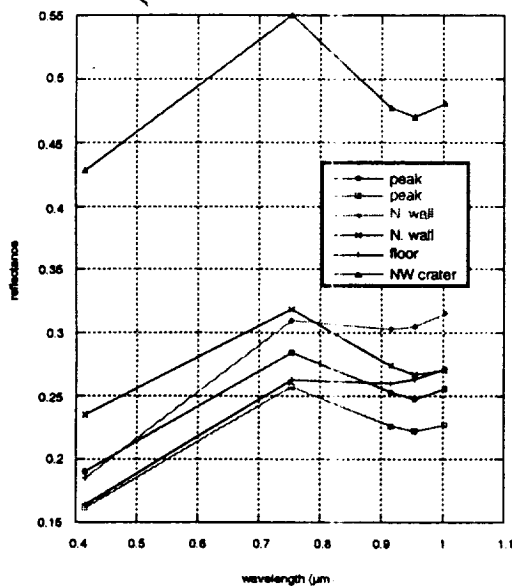


Figure 3: Selected spectra for Stevinus. Note the strong mafic absorption band for the central peaks and part of the north wall. The small fresh crater NW of Stevinus has a significantly brighter spectrum with a strong mafic absorption band; the small crater to the SE is similar (not shown).

Discussion: Stevinus and Jackson are similar in size, age, and geologic setting (Table 1), and both appear to have formed from impacts into areas that contain pyroxene-bearing lithologies (anorthositic gabbro-norite to anorthositic norite) at depths of 11 – 12 km. At Stevinus, this mafic unit may extend vertically to near-surface depths and laterally to >100 km from the crater center, with a relatively uniform composition

throughout. At Jackson, the mafic unit appears to be lower in FeO than at Stevinus, and is intermingled with a more anorthositic unit in both the peaks and walls. Outside the crater, however, only anorthositic lithologies have been exposed.

Conclusions and Future Directions: Set in regions well removed from obvious volcanic activity, the material exposed in the central peaks and walls of craters such as Stevinus and Jackson is expected to represent crust formed during the crystallization of the magma ocean and during any subsequent magmatic intrusion. Craters with mafic lithologies are rare in the highlands [2], but where they do occur there is evidence for large (10's – 100's of km), near-surface (0 – 15 km depth) units of relatively uniform composition.

Continuing work with the craters listed in Table 1 will focus on further constraining the composition, extent and origin of mafic units within the highlands, using other remote sensing data (e.g., NIR telescopic spectra where available, Lunar Prospector elemental abundance maps) for further insight.

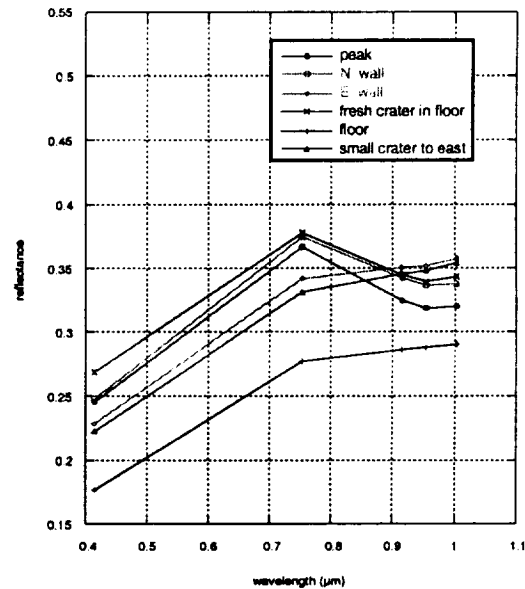


Figure 4: Selected spectra for Jackson. Note the similar shape of the absorption bands in the three most reflective (at .75μm) spectra to Stevinus spectra. The shape is affected by the type of mafic minerals present, and for these two craters both high-Ca and low-Ca pyroxene may be present.

References: 1. Lucey, P.G., et al., *Science*, 1995. 268: 1150-1153. 2. Tompkins, S. and C.M. Pieters, *M&PS*, 1999. 34: 25-41. 3. Wieczorek, M.A. and M.T. Zuber, *Geophysical Research Letters*, 2001. in press. 4. Korotev, R.L., *J. G. R.*, 2000. 105(E2): 4317-4345. 5. Cintala, M.J. and R.A.F. Grieve, *M&PS*, 1998. 33: 889-912. 6. Lucey, P.G., et al., *J. G. R.*, 1998. 103(E2): 3679-3699.

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